

Leksell Gamma Knife Perfexion과 Model C의 치료계획 효용성 비교 : 임상연구

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Comparison of Efficiency in Dose Planning of the Leksell Gamma Knife Perfexion and Model C : Clinical Study

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ABSTRACT

Objective : The purpose of this study was to compare the dose planning between the Leksell Gamma Knife Perfexion (LGK PFX) and the Leksell Gamma Knife C (LGK C) using variable indices.

Methods : A total of 100 cases, which were composed of 35 meningiomas, 20 vestibular schwannomas, 35 metastases, and 10 pituitary adenomas, were enrolled in this study. First, these cases were treated with the LGK PFX and then, were re-planned with the LGK C. We compared these two models in terms of the number of shots, the percentage of coverage, the conformity index (CI), Paddick's conformity index (PCI), the gradient index (GI), and the beam on time.

Results : The LGK PFX completely outperformed the LGK C in terms of GI and the LGK PFX tended to have a longer beam on time than that of the LGK C. However, in patients with schwannomas, the LGK PFX outperformed the LGK C in terms of the CI, PCI, and GI, and in patients with pituitary adenomas, the LGK PFX outperformed the LGK C in terms of the percentage of coverage, PCI, and GI with statistical significance.

Conclusion : The LGK PFX is an entirely redesigned radiosurgery unit accompanied by the development of software. The LGK PFX is supposed to achieve highly conformal dose prescription consisting of many isocenters with a reasonable treatment time.

KEY WORDS : Radiosurgery · Gamma Knife · Dose planning · Perfexion · Model C.

Introduction

Since the Leksell Gamma Knife (ELEKTA Instruments AB, Stockholm, Sweden)(LGK) was first developed in 1967, newer versions of the machine have been developed as a series of the

LGK models including A, B, C, and 4-C. Recently, the Leksell Gamma Knife Perfexion (LGK PFX), an entirely redesigned unit, was introduced in 2006.

The LGK PFX has many different features from previous models of the LGK. First, as far as the radiation unit itself, the source geometry has been changed to an array of 192 Cobalt-60 sources, arranged in a cone section configuration. Additionally, the collimators have been replaced by a single, larger, 12-cm-thick tungsten collimator array, subdivided into eight sectors. The 4- and 8-mm collimators remain, but the 14- and 18-mm collimators have been replaced with 16-mm collimators, and

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the beam diameters are automatically changed. In comparison with previous models, the LGK PFX shows a greater treatment range of more than three times, in the x and y dimensions of 160 mm (x, 20–180 mm) and 180 mm (y, 10–190 mm).

Second, instead of adjusting the collimator helmet, the patient positioning system (PPS) moves the patient to the preselected stereotactic coordinates. The PPS moves faster than the automatic positioning system (APS) at speeds of up to 10 mm/s.

Third, the dose planning software was updated as the Leksell GammaPlan PFX (LGP PFX). Compared to previous versions of the LGP, the LGP PFX accommodates improved image fusion, nearly instantly on the previous treatment plan for new planning images, simplified dose prescription for multiple matrices, and decreased doses to critical structures using sector blocking, hybrid shots (also known as composite shots), and a unique process called dynamic shaping.¹⁾

With these evolutions of hardware and software, the LGK PFX has been known to have radiobiological benefits such as increased conformity, improved accuracy, decreased normal tissue irradiation, and reduced treatment time. The purpose of this study was to compare dose planning between the LGK PFX and the LGK C using variable indices.

Materials and Methods

1. Patient population

From November, 2008 to March, 2009, a total of 250 cases were treated with the LGK PFX in our center. Among the cases, 100 cases with a size larger than 4 mm³, were eligible for this study. Pathologically, cases were composed of 35 meningiomas, 20 vestibular schwannomas, 35 metastases, and 10 pituitary adenomas. First, these cases were treated using the LGK PFX with the LGP PFX version 8.3, and then were re-planned with LGK C with LGP 5.34. Adjustment of the dose rate was carried out between the two models.

2. Evaluation parameters

All paired plans (LGK PFX with the LGP PFX version 8.3 and LGK C with the LGP 5.34) were compared for the mean values of the number of shots, percentage of coverage, the conformity indices (CI) as described by Shaw et al.⁶⁾ and Paddick (PCI),³⁾ the gradient index (GI) as described by Paddick and Lippitz,⁴⁾ and the beam-on time. The conformity index (CI)⁶⁾ was defined as :

$$CI = \frac{PIV}{TV}$$

where PIV was the volume covered in prescription isodose, and TV was the defined target volume. The Paddick conformity index (PCI)³⁾ used the target volume covered in the prescription dose (TV_{PIV}), and was defined as :

$$PCI = \frac{(TV_{PIV})^2}{TV \times PIV}$$

The gradient index as described by Paddick and Lippitz was the ratio of the volume of half the prescription isodose to the volume of the prescription isodose, and was defined as :

$$GI = \frac{PIV_{25\%}}{PIV_{50\%}}$$

where PIV_{25%} and PIV_{50%} are the 25% and 50% isodose volume, respectively.

Results

For the entire patient group, there was a statistically significant difference between the LGK PFX and the LGK C in terms of the number of shots (25.5 vs. 20.4), GI (2.640 vs. 2.786), and beam on time (68.7 vs. 59.9). There was no significant difference between the two models for the percentage of coverage, CI, and PCI.

However, there was a different trend in the subgroup analysis. In vestibular schwannomas, the LGK PFX outperformed the LGK C in terms of the CI (1.052 vs. 1.105), PCI (0.916 vs. 0.864), and GI (2.63 vs. 2.75), whereas there was no significant difference in the number of shots, the percentage of coverage, and the beam on time. In the pituitary adenomas subgroup, the LGK PFX outperformed the LGK C in terms of the percentage of coverage (97.3 vs. 95.1), PCI (0.825 vs. 0.782), and GI (2.67 vs. 2.86). In the meningiomas and metastases subgroups, there was similar trend with the total group, in which the LGK PFX outperformed the LGK C in terms of GI. The outcomes for the dose-planning parameters of the LGK PFX with the LGP PFX version 8.3 and the LGK C with the LGP 5.34 were summarized in Table 1.

Discussion

When the treatment modality has radiological benefits, it refers to versatile planning, increased conformity, increased accuracy (or sensitivity), decreased irradiation of normal tissue, and decreased treatment time. In the present study, the LGK PFX outperformed the LGK C in terms of selectivity and showed a similar performance in terms of conformity. Additionally, in the LGK PFX, the number of shots was larger, and the beam on

Table 1. Comparison of dose-planning using the LGK C with the LGP 5.34 and the LGK PFX with the LGP PFX version 8.3

	No. of shots	Coverage (%)	CI	PCI	GI	Beam on time (min)
Meningioma (n=35, TV : 5.6 mm ³)						
C	18.7*	99.7	1.113	0.892	2.80*	43.1*
PFX	26.5*	99.7	1.082	0.924	2.66*	61.7*
Schwannoma, VIII (n=20, TV : 5.2 mm ³)						
C	22.6	98.6	1.105*	0.864*	2.75*	71.7
PFX	24.9	98.8	1.052*	0.916*	2.63*	77.5
Metastasis (n=35, TV : 11.6 mm ³)						
C	19.4*	99.9	1.241	0.792	2.73*	45.3*
PFX	25.4*	99.9	1.198	0.801	2.60*	52.7*
Pituitary adenoma (n=10, TV : 4.7 mm ³)						
C	23.1	95.1*	1.163	0.782*	2.86*	79.3
PFX	23.5	97.3*	1.152	0.825*	2.67*	82.8
Total (n=100, TV : 7.3 mm ³)						
C	20.4*	99.1	1.155	0.834	2.786*	59.9*
PFX	25.5*	99.3	1.122	0.866	2.640*	68.7*

* : statistically significant, p-value <0.05. LGK C : Leksell Gamma Knife C, LGP : Leksell GammaPlan, LGK PFX : Leksell Gamma Knife Perfexion, LGP PFX : Leksell GammaPlan Perfexion, CI : conformity index, PCI : Paddick conformity index, GI : gradient index, TV : target volume

Table 2. Performance summary of the LGK PFX compared to the LGK C

	No. of shots	Conformity	Selectivity	Beam on Time
Meningioma	More	Almost same	Better	Longer
Schwannoma	Almost same	Better	Better	Almost same
Metastasis	More	Almost same	Better	Longer
Pituitary adenoma	Almost same	Better	Better	Almost same
Total	More	Almost same	Better	Longer

LGK PFX : Leksell Gamma Knife Perfexion, LGK C : Leksell Gamma Knife C

time was longer than in the LGK C (Table 2).

In the LGK PFX, the 14-mm and 18-mm collimators were replaced with 16-mm collimators. In the previous study, the 14-mm and 18-mm collimators were used for only 8.4% and 1.4% of isocenters in dose planning with the LGK C.¹⁾ Therefore, it was reasonable to replace the collimators, and it was possible to make highly conformal shots with more isocenters. The 4-mm collimator was used very selectively with the LGK C, while it was applied liberally for the LGK PFX.²⁾ Similarly, dynamic shaping by sector blocking was used frequently in the LGK PFX. These factors resulted in an increased number of shots, and subsequently increased the beam on time.

Generally, the overall treatment time consists of the set-up time and beam on time. In the present study, measurement of set-up time was not possible ; however the overall treatment time was probably shorter in the LGK PFX than in the LGK C. The set-up time includes time that is used in the initial docking of the patient, position check, coordinate setting in the APS mode, collimator change, change from low to high docking, change from APS to trunnion mode, coordinating setting in the

trunnion mode, initial/final couch move in the treatment position, and coordinate and sector change (only in the LGK PFX).²⁾ In the LGK PFX, PPS moves faster than APS in the LGK C up to a rate of 10 mm/s and there is no time penalty for changing a collimator helmet as in the LGK C. Automatic coordinate and sector change take less than 1 second. Even though in the present study, the beam on time increased in the LGK PFX, which was because of an increased number of shots and blocking sectors, the overall treatment time was supposed to be shorter in the LGK PFX because of the treatment efficacy. Previous studies supported our assumption.^{1,2,5)}

In the subgroup analysis, the LGK PFX outperformed the LGK C in terms of conformity and the percentage of coverage for vestibular schwannomas and pituitary adenomas. These kinds of tumor are generally surrounded by eloquent structures including optic nerves and other cranial nerves. The new version of the LGP PFX can generate various shapes originating from a single isocenter using the composite shot feature. Once the critical structure is defined, a so called “risk volume”, the composite shot feature makes various beam shaping as the lev-

el of dose to the risk volume using dynamic shaping or sector blocking. In the recent study, the LGK PFX showed better performance in terms of conformity and energy distribution than the LGK C with sparing cochlear function.⁷⁾ Therefore in a case where the target is surrounded by important structures, the LGK PFX is a reasonable choice showing a better conformity and the percentage of coverage than that of the LGK C. Additionally, in terms of selectivity, which means how well the prescribed dose is fitted not only to the target volume but also to normal tissues, the LGK PFX can achieve high selectivity (Table 2).

Conclusion

The LGK PFX is an entirely redesigned radiosurgery unit accompanied by the development of new software, as the LGP PFX. New feature of this unit include an increased mechanical treatment range, automatic change and adjustment of collimators, and replacement of 14- and 18-mm collimators to 16-mm collimator. In the present study, the LGK PFX showed a similar conformity to the LGK C with longer beam on time and an increased number of shots. However, for pituitary adenomas and vestibular schwannomas, the LGK PFX outperformed the LGK C in terms of conformity and selectivity. The LGK PFX was supposed to achieve highly conformal dose prescription consisting of many isocenters with a reasonable treatment time.

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